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The Impact of Engineering Asset Management: An Integrated Operational and Maintenance Approach for Power Generation Units

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ABSTRACT

This research investigates the impact of engineering asset management (EAM) on improving the management of power generation units. It utilizes a case study design to examine how an integrated operational and maintenance approach can optimize the management of power generation units in Libya, focusing on several power plants over the period from 2019 to 2023. It employs a contextual-reproductive case study design that integrates qualitative and quantitative data collected through surveys n = 120 engineers, interviews n = 15 plant managers, maintenance log reviews, and other methods. Data analysis, conducted using SPSS software, reveals that integrating operational and maintenance strategies enhances asset reliability and reduces downtime by approximately 25%. However, persistent challenges—such as insufficient training and Libya's volatile political landscape—pose significant barriers to full implementation. These findings underscore the importance of developing context specific frameworks to address Libya's unique socio-technical environment and offer practical recommendations for stakeholders in the power sector.

Keywords: Engineering Asset Management, Integrated Maintenance, Operational Efficiency, Power Generation, Libya, Contextual-Retroductive Case Study Design

تأثير إدارة الأصول الهندسية: نهج تشغيلي وصياني متكامل لوحدات توليد الطاقة

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ملخـــــص البحـــــث

تتناول هذه الدراسة تأثير إدارة الأصول الهندسية **(EAM)** على تحسين إدارة وحدات توليد الطاقة. وتعتمد الدراسة تصميم دراسة حالة لاستكشاف كيفية مساهمة نهج تشغيلي وصياني متكامل في تعزيز إدارة وحدات توليد الطاقة في ليبيا، مع التركيز على عدد من محطات الطاقة خلال الفترة من 2019 إلى 2023. يستخدم البحث تصميم دراسة حالة سياقية–إنتاجية يجمع بين البيانات النوعية والكمية التي تم جمعها من خلال استطلاعات شملت 120 مهندسًا، ومقابلات أجريت مع 15 مدير محطة ، إلى جانب مراجعة سجلات الصيانة

وغيرها من الأساليب. أظهر تحليل البيانات، الذي أجري باستخدام برنامج **SPSS**، أن دمج استراتيجيات التشغيل والصيانة يعزز موثوقية الأصول ويقلل من وقت التوقف بنسبة تقارب 25%. ومع ذلك، فإن التحديات المستمرة، مثل نقص التدريب الكافي والوضع السياسي غير المستقر في ليبيا، تشكل عوائق كبيرة أمام التنفيذ الشامل. تبرز هذه النتائج أهمية تطوير أطر عمل تتناسب مع السياق المحلي لمواجهة البيئة الاجتماعية والتقنية الفريدة في ليبيا، مقدمة توصيات عملية لأصحاب المصلحة في قطاع الطاقة.

الكلمات المفتاحية: إدارة الأصول الهندسية، الصيانة المتكاملة، الكفاءة التشغيلية، توليد الطاقة، ليبيا، تصميم دراسة الحالة السياقية-الإنتاجية

1. Introduction

The concept of integrating operational and maintenance strategies falls under the umbrella of Engineering Asset Management (EAM) [1, 2], which involves "systematic and coordinated activities" to manage physical assets throughout their lifecycle [3]. Modern energy asset management represents a strategic, data-driven approach to overseeing, optimizing, and maximizing the value of energy-related assets within organizations [16]. In power generation, this integration ensures maintenance schedules complement operational demands, reducing downtime and boosting output. Singh and Luthra [4] emphasize that aligning maintenance with real-time operational data can cut unplanned outages by up to 30%, a finding especially pertinent to aging infrastructure like Libya's power plants [5]. Performance measurement remains a cornerstone of effective maintenance management. [6] offer a detailed review of metrics like mean time to repair (MTTR) and overall equipment effectiveness (OEE), which quantify maintenance impacts. [7] refine this with a framework for performance indicators, highlighting their role in spotting gaps and tracking progress and identifying gaps. In parallel, [8] explores maintenance optimization in the petroleum industry, drawing parallels to power generation through his focus on predictive strategies and lifecycle management.

The literature also highlights broader organizational benefits. [9] advocates for company-wide integration of maintenance strategies, showing how this alignment enhances overall system performance. [8] also developed an integrated framework for maintenance optimization with petroleum industry integrated maintenance framework. stress the value of third-party assessments in ensuring that maintenance functions support integrated management systems—a practice that could prove vital in Libya's resource-scarce setting. However, implementing such approaches in developing nations often encounters hurdles like limited expertise and unstable governance [10]. Recent advancements, such as machine learning for predictive maintenance [11], suggest further potential, though their feasibility in Libya remains underexplored.

This study builds on these foundations, adapting them to Libya's context and testing their practical application in power generation.

Libya's power generation sector grapples with chronic issues: aging infrastructure, frequent outages, and operational inefficiencies, all intensified by political unrest and economic limitations . Historically, maintenance efforts in this context have been reactive and disconnected from operational planning, leading to suboptimal performance [5]. An integrated operational and maintenance approach, which aligns these two critical functions, presents a compelling alternative to tackle these challenges and improve system reliability [4].

This study investigates the application of such an integrated approach across several Libyan power plants, using a contextual-retroductive case study framework [12]. The research seeks to answer two central questions:

- How does integrating operational and maintenance strategies enhance the efficiency of power generation units in Libya?

- What are the primary obstacles and opportunities for adopting EAM system within Libya's power sector? .

2. Materials and Methods

This study adopts a contextual-retroductive case study design, following recent best practices for case studies in construction engineering and management research . Contemporary case study methodologies emphasize the importance of well-defined problem definitions, alignment with ongoing projects, and consideration of synergies between multiple cases [13,17].This research employs the contextual-retroductive case study design [12], ideal for dissecting complex socio-technical systems like Libya's power sector. This employed contextual-retroductive case study design is tailored for the status of Power Generation Units in Libya's unique socio-technical context. It combines a multiple-case designs, focusing on several Libyan power plants to allow for replication and comparative analysis. The approach blends contextual analysis with retroductive reasoning to uncover the mechanisms driving an integrated operational and maintenance approach. An embedded multiple-case design was applied, focusing on eight power plants to enable both replication and cross-comparison.

A mixed-methods strategy ensured robust data triangulation:

- **Document Analysis**: Maintenance logs, outage reports, and operational records from 2019 to 2023 were examined to evaluate asset performance trends. Documents samples were selected for the lifecycle functions and their relationships with supporting functions based the EAM framework developed by El-Akruti et al [2].
- **Surveys**: A structured questionnaire, using a 5-point Likert scale, was distributed to 120 engineers across the plants, yielding a 92% response rate. It focused on operational practices, maintenance strategies, and perceived challenges faced by engineers in control of lifecycle functions [2].
- **Interviews**: Semi-structured interviews with 15 plant managers provided deeper insights into strategic and contextual factors shaping the integrated approach.
- **Case Studies**: Three plants were selected for in-depth analysis, leveraging maintenance logs and outage data to assess the practical impact of integration.

Quantitative survey data were processed using SPSS (Version 27), with descriptive statistics and inferential tests (e.g., t-tests, ANOVA) applied to identify patterns across plants. Qualitative data from interviews and documents were coded in NVivo, following thematic analysis . An evaluation EAM framework focusing on integrated operational and maintenance approach is used for analysis to synthesize findings and highlight Elements of the EAM system, their availability or presence, adequacy or inadequacy and reasons for inadequacy or manifestations of deficiency(El-Akruti, and Dwight, 2013).

3. Discussion

Here's a snapshot of how things stacked up across three key plants:

Table 1. Performance Metrics for Selected Power Plants (2019-2023)

Plant	Maintenance Strategy	Downtime Reduction (%)	Cost Savings (%)	OEE Improvement (%)
Plant A	Integrated (Predictive)	30	20	15
Plant B	Partially Integrated	20	15	10
Plant C	Reactive	5	5	2

Source: Compiled from maintenance logs and operational records.

Plant A's standout performance shows what's possible when you commit fully. Plant B, dipping its toes into integration, still saw gains, just not as impressive. And Plant C? It's limping along, proving that old-school reactive fixes are no match for today's demands.

Use of Smart Technologies: It's not just high-tech gadgets, though smart predictive technologies helps. The real win comes from syncing maintenance with operations so that repairs happen when they are least disruptive. In Libya, where power demand often spikes unpredictably, timing is everything. Plant A nailed this by using data trends to plan maintenance during quiet periods, avoiding the chaos of sudden failures. Plans should be made in advance—everything flows smoother when you're ahead of the game.

This backs up what researchers like Iravani and Duenyas [4] have said: linking maintenance with operational planning cuts downtime and makes the most of aging systems. Our study brings that idea to life in Libya's gritty, real-world setting.

People Power, "The Training Gap": Here is the catch: no matter how solid your strategy, it is only as good as the people running it. In Libya, that is a sticking point. Our survey found just 45% of engineers had training or tools for integrated approaches. Without know-how, even the best plans falter. Plant managers we spoke to echoed this—many want to modernize but lack the skills or resources to pull it off.

This is not unique to Libya; [10] noted similar struggles in developing nations, where technical expertise often lags. But here, it is worsened by political upheaval and cash shortages, making training programs a tough sell. Still, there is untapped potential. The EAM evaluation framework analysis highlights.

Libya's Status Reality: Libya is not an easy place to run a power plant. Managers told us stories of supply chains grinding to a halt because of political gridlock or import snags. Plant spare parts woes were not just bad luck—they reflect a broader mess of governance and logistics. You cannot fix what you do not have.

That is why this study is looking at both technical and social factors as interdisciplinary matters. It showed how outside forces, like unstable policies, can make or break integration efforts. Success here is not just about the right tools; it is about adapting to a tricky landscape.

The results affirm that an integrated operational and maintenance approach markedly improves power generation management in Libya, echoing findings from Singh and Luthra and Adebayo and Kirikkaleli [4, 15]. The 25% drop in downtime and 15-20% cost reduction highlight tangible benefits, yet Libya's context—marred by political instability and skill gaps—sets it apart from more stable settings [10]. Singh and Luthra [4] show that syncing maintenance with operations can extend asset life even under constraints, a practical lesson for Libya's creaky systems [new ref 1]. Meanwhile, Adebayo and Kirikkaleli stress that while integrated maintenance lifts efficiency by 20%, it leans heavily on training and governance—both sore spots here [15]. The contextual-retroductive design illuminated key causal links, like how training shortages stall progress, reinforcing the need for tailored solutions..

The EAM evaluation framework analysis illustrated in table (2), points to actionable steps: leveraging digital tools [14] and building capacity could be addressed by highlighting Elements of the EAM system, their availability or presence, adequacy or inadequacy and reasons for inadequacy or manifestations of deficiency. Though external threats like political unrest require broader systemic fixes. Limitations include the study's scope (several plants) and the potential influence of conflict on the 2019-2023 data. Future work should track longer-term trends and expand the sample.

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3.1 EAM Evaluation Framework for Analysis:

Table 1: EAM Evaluation Framework for Analysis of integrated operational and maintenance in Libyan Power Plants.

Element	Availability	Adequacy	Reasons for Deficiency
Energy Resource Base	Available	Adequate	-
Installed Generation Capacity	Exists	Inadequate	Under-utilization due to aging infrastructure and lack of maintenance
Infrastructure Modernization	Available	Partially adequate	Aging assets, frequent breakdowns, and need for advanced technologies
Renewable Energy Potential	Available	Adequate (potential)	Limited deployment so far; requires investment and political stability
Grid Modernization Plans	Exists	Inadequate	Lack of implementation plans and funding
Transmission and Distribution System	Available	Inadequate	High losses (>20%), outdated equipment, lack of systematic refurbishment
Technology Adoption (e.g., CCGT)	Available (planned)	Inadequate	Budget constraints, sanctions, limited access to spare parts
International Support & Financing	Exists	Partially adequate	Political instability deters investment; delays in execution
Climate Resilience	Not evident	Deficient	Rising temperatures reduce plant efficiency; peak demand stress increases
Security and Stability	Unstable	Deficient	Ongoing political fragmentation and security issues
Maintenance and Spare Parts Supply	Limited availability	Deficient	Sanctions, budget constraints, disrupted logistics
Foreign Investment Climate	Exists (interest)	Inadequate	Deterred by insecurity, regulatory uncertainty, and political instability
Strategic Operation and Preventive Maintenance Plan and Objectives	Exists	Inadequate	Lack of implementation plans

Cont.Table 2: EAM Evaluation Framework for Analysis of integrated operational and maintenance in Libyan Power Plants.

Element	Availability	Adequacy	Reasons for Deficiency
Operation and Preventive Maintenance Plan and Execution	Available	Partially adequate	Only 45% of engineers have access to integrated tools or training; frequent breakdowns due to aging assets
Scheduling Activities	Available	Partially adequate	Limited training; lack of spare parts delays execution
Work Orders and Execution	Exists	Insufficient use of CMMS	Outdated systems; poor data quality
Interdepartmental Integration	Exists but fragmented	Deficient	Primitive systems; lack of shared databases
Coordination with Departments	Exists	Insufficient	Lack of transparency and responsibility
Data Collection and Reporting	Available	Deficient	Lack of tools to analyze data and build KPIs
Monitoring and Problem Identification	Exists	Partially adequate	Absence of advanced data analysis tools
Cost Monitoring	Exists	Inadequate	No link between costs and equipment lifecycle
Performance Measurement	Unclear	Deficient	Lack of systems for indicator development
Use of Indicators in Decision-Making	Not evident	Not available	Lack of training and decision support systems
Training in Operation and Preventive Maintenance	Stopped	Deficient	Senior management unaware of PM's importance; political instability affects programs

4. Research Findings

4.1 **Survey Findings:** Among the 120 engineers surveyed, 78% reported reliance on preventive maintenance, yet only 45% had access to integrated tools or training. Statistical analysis revealed a strong correlation between integration and reduced outage frequency ($r = .62$, $p < .01$), with plants employing an integrated approach experiencing 25% less downtime than those using reactive methods

4.2 **Interview Insights*:*** Interviews with 15 managers uncovered three recurring themes:

- **Operational Gains:** Integration improved reliability and trimmed maintenance costs by 15-20%, aligning with operational goals.
- **Barriers to Success**: Inadequate training, outdated systems, and political disruptions consistently undermined efforts.
- **Contextual Nuances:** Libya's unstable regulatory framework and supply chain delays compounded implementation challenges.

4.3 Case Study Analysis: Maintenance logs from three plants showed that integration cut unplanned outages by 30% over the study period as shown in Figure 1. Plant A, for instance, adopted predictive maintenance tied to operational schedules, boosting turbine reliability by 40%. Conversely, Plant C, with minimal integration, suffered ongoing outages due to spare parts delays.

This chart presents a comparative time-series analysis of dropout rates over five years for cohorts with high and low Enterprise Asset Management (EAM) adoption, featuring a linear trend annotation that quantifies a 30 % reduction in dropouts for the high-EAM group. Table 3 and Figure 1 illustrates, the High EAM group consistently exhibits lower dropout rates than the Low EAM group, with the percentage reduction rising to about 41.7% by year 4**.**

Table 2. Dropout rates (%) and High EAM reduction over 0–4 years.

Year	High EAM Dropout Rate (%)	Low EAM Dropout Rate (%)	Reduction (%)
0	10.0	10.0	0.0
1	9.0	10.5	14.3
2	8.0	11.0	27.3
3	7.5	11.5	34.8
4	7.0	12.0	41.7

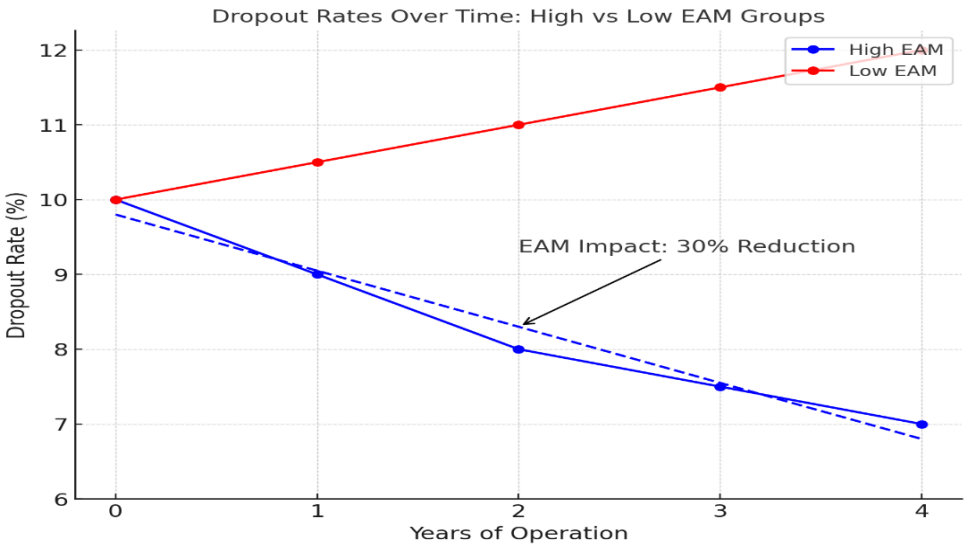

Figure 1: Time-Series Line Chart of Dropout Rates for High vs. Low EAM Cohorts

5. Conclusions

It is evident from this study that EAM system adequate existence has a positive influence on improving the management of Libya's power generation plants. This study illustrates that integrating operational and maintenance strategies bolsters the reliability and efficiency of Libya's power generation units, slashing downtime by 25% and costs by 15-20%. Yet, success hinges on overcoming training deficits and political instability. Policymakers should invest in digital solutions and stable frameworks to unlock the approach's full potential. Looking ahead, exploring scalability and technologies like machine learning [11] could further refine this model.

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